Relationships Among Metals Criteria, Ambient Bioassays, and Community Metrics in Metals-Impaired Streams

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Abstract

If bioassessments are to help the Office of Water, the Regions and the States to diagnose causes of stream impairments, a better understanding is needed of the relationship between community metrics and ambient criteria or ambient bioassays. This relationship is not simple, because metrics assess responses at the community level of biological organization, while ambient criteria and bioassays assess or are based on responses at the individual level. For metals, the relationship is further complicated by the influence of other variables, such as hardness, on their bioavailability and toxicity. In 1993 and 1994, a R-EMAP survey was conducted on streams in Colorado's Southern Rockies Ecoregion. In this ecoregion, mining has resulted in metals contamination of streams. The surveys collected data on fish and macroinvertebrate assemblages, physical habitat, and sediment and water chemistry and toxicity. These data provide a framework for assessing diagnostic community metrics for specific environmental stressors. We characterized streams as metals-impaired based on exceedence of hardness-adjusted metals criteria (Cd, Cu, Pb, and Zn) in water; on water toxicity tests (48-hour *Pimephales promelas* and *Ceriodaphnia dubia* survival); on exceedence of sediment TELs; or on sediment toxicity tests (7-day *Hyalella azteca* survival and growth). Macroinvertebrate and fish metrics were compared among affected and unaffected reaches to identify metrics sensitive to metals. Several macroinvertebrate metrics, particularly richness metrics, were less in impaired streams, while other metrics were not. This is a function of the sensitivity of the individual metrics to metals effects. Fish metrics were less sensitive to metals, because of the low diversity of fish in these streams.

Introduction

The objectives of this research are to compare conclusions about the effects of contaminants at different reaches using the three primary methods for the ecological assessment of contaminant exposure and effects in waters or sediments:

(1) chemical criteria - AWQCs or sediment effect levels - for the protection of aquatic life,
(2) bioassays to assess ambient toxicity of water or sediment, and
(3) bioassessments of fish or macroinvertebrate assemblages.

In this paper, this approach is applied to streams affected by metals associated with hard rock mining in Colorado's Southern Rockies Ecoregion.

Because of their differing measurement endpoints, these methods assess different levels of biological organization. Chemical criteria and ambient bioassays are based on measures of the responses of individuals and show individual- or population-level effects. Bioassessments show community-level effects. Chemical criteria and ambient bioassays differ, because chemical criteria are based on bioassays with a range of taxa, whereas ambient bioassays use a few standard species.

Assumptions exist about the relationships between the levels of protection associated with these assessment tools. Bioassays measure individual endpoints, such as mortality, growth, or reproduction, tied to populations, because mortality and reproduction affect population size. Chemical criteria are assumed to be protective of at least 95% of the taxa in aquatic communities, because thresholds are set at the 5th percentile of the most sensitive genera in the sensitivity distribution. Protection at the community level for ambient bioassays maybe variable, because of variable sensitivity of the standard species relative to indigenous taxa. Continued use of these methods in ecological assessment and management of environmental contaminants can benefit from greater understanding of the relationships between these levels of biological organization and their protection by the endpoints measured by these methods.

Methods

The R-EMAP survey of the mineral belt of the Colorado's Southern Rockies Ecoregion selected
73 wadeable stream reaches using a spatially systematic, randomization method (Figure 1). 13 additional reaches were selected upstream or downstream of mining sites.

- Water was analyzed for dissolved metals and hardness and sediments for total metals
- 48-hr mortality tests (*Ceriodaphnia dubia* & *Pimepheles promelas*) were conducted with water and 7-day growth and mortality tests (*Hyallela azteca*) for sediments.
- Macroinvertebrates and fish were collected following EMAP methods (Lazorchak et al. 1998), Only data from riffle macroinvertebrate samples were used.
- Assemblage data were used to calculate various metrics. Fish metrics were limited by the low, natural diversity of the fish assemblages.
- Sampling events were classified into two groups, those affected or unaffected by metals in water or sediments. The events were segregated four times, each based on one of the four individual-effects based methods (Table 1).
- Assignments of reaches to groups were compared between water and sediments and between the ambient criteria and bioassays with contingency tables; the index was used to assess the correspondence between groups. The index γ is a measure of association in the assignment of reaches ranging from -1 to +1.
- Metrics were compared between each pair of groups with a one-way ANOVA to answer the question, "Was the mean of the metric different between groups identified as affected or unaffected by metals?"
- We quantified the frequency of disagreement between an assessment of reaches based on individual effects and that based on the metrics.
- Segmented regression was used to further explore the relationships between metrics and metals relative to ambient criteria. Segmented regression models data where the regression changes at points, called join points. If the criteria for water or sediments represent thresholds for community-level effects as measured by the metrics, then the the regression should change at the join point, where at least one metal exceeded its criterion.

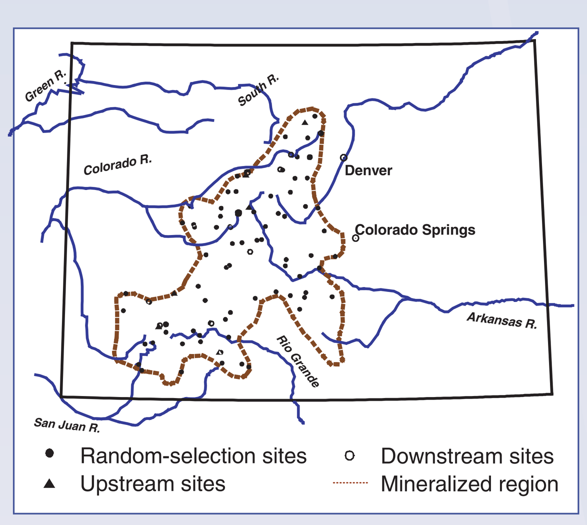

Figure 1. Map of Colorado with the mineralized region of the Southern Rockies Ecoregion and locations of the 1994 – 1995 R-EMAP reaches.

Table 1. Criteria used to segregate reaches into affected or unaffected groups.

Variable	Individual Criterion	Source
Dissolved concentrations - Cd, Cu, Pb, or Zn	>Hardness-adjusted dissolved chronic criteria	USEPA (1999, 2001)
Survival of *C. dubia* or *P. promelas* (48-hr test)	<80% survival	control tests
Sediment concentrations - Cd, Cu, Pb, or Zn	>TEL for 28-d *H. azteca* sediment toxicity test	USEPA (1996)
Survival or growth of *H. azteca* (7-day test)	<85% survival or 90% growth	control tests

Results

Table 2. Correspondence of conclusions of assessments for water and sediment and based on criteria and bioassays for sampling events.

A. MEDIA Criteria (γ = +0.89)		Were water criteria exceeded?			B. METHODS Water (γ = +0.98)		Were metal ambient water quality criteria (AWQC) exceeded?		
		No	Yes	Total			No	Yes	Total
Were sediment threshold-effects levels (TELs) exceeded?	No	53	3	56	Did water bioassays show effects?	No	65	8	73
	Yes	15	15	30		Yes	1	10	11
	Total	68	18	n = 86		Total	66	18	n = 84
Bioassays (γ = +0.83)		Did water bioassays show effects?			Sediment (γ = +0.73)		Were metal sediment threshold effects levels (TELs) exceeded?		
		No	Yes	Total			No	Yes	Totals
Did sediment bioassays show effects?	No	63	4	67	Did sediment bioassays show effects?	No	49	18	67
	Yes	10	7	17		Yes	5	12	17
	Total	73	11	n = 84		Totals	54	30	n = 84

Table 3. Metrics exhibiting differences between two groups segregated using at least one of the following measurement endpoints: chronic AWQC for dissolved Cd, Cu, Pb, or Zn; results of 48-hr, water bioassays (*C. dubia* or *P. promelas*); sediment TELs for Cd, Cu, Pb, or Zn (28-day *H. azteca* tests); or results of 7-day sediment bioassays (*H. azteca*).

Macroinvertebrates	Tanytarsini taxa richness	Shredder taxa richness
Total taxa richness	Coleoptera taxa richness	Scraper taxa richness
Total abundance	% Ind., Ephemeroptera	**Fish**
Abundance per taxon	% Orthocladinae of Chironomidae	Total species richness
Intolerant taxa richness	% Tanytarsini of Chironomidae	Salmonidae species richness
Ephemeroptera taxa richness	% Ind., Coleoptera	Total abundance
Plecoptera richness	% Ind., Diptera and noninsects	Adult abundance
Trichoptera taxa richness	% Ind., Most common taxon	Salmonidae abundance
EPT taxa richness	% Ind., Five most common taxa	% Ind., native species
Chironomidae taxa richness	Collector-filterer taxa richness	% Ind., Salmonidae
% Ind., tolerant taxa	Collector-gatherer taxa richness	% Ind., native Salmonidae
Orthocladinae taxa richness	Predator taxa richness	% *Oncorhynchus* of Salmonidae

- Criteria or bioassays indicated sediments were toxic, while water was not at more reaches than the reverse (Table 2A). Based on the chemistry of the mine drainage, some reaches would be expected to have elevated concentrations of metals in sediment but not water.
- Criteria indicated water or sediments were toxic while bioassays did not at more reaches than in the reverse (Table 2B).
- Several macroinvertebrate metrics exhibited differences between groups segregated using the individual-based measures (Table 3). This seems to depend on the sensitivity of the metrics to metals. Metrics with the greatest F statistics were generally richness metrics (Table 3, Figure 1)
- Richness metric sensitivity to metals is consistent with an assumption that individual-and population-level effects are the basis of community-level effects. Toxicants increase mortality and decrease growth and reproduction of individuals, and this reduces population abundances. At increasing thresholds, recruitment of different populations fails, species are sequentially eliminated from the assemblage, and taxa richness decreases.
- Fish metrics were less sensitive to the metals (Table 3, Figure 1), likely a result of the low fish diversity in these coldwater streams.

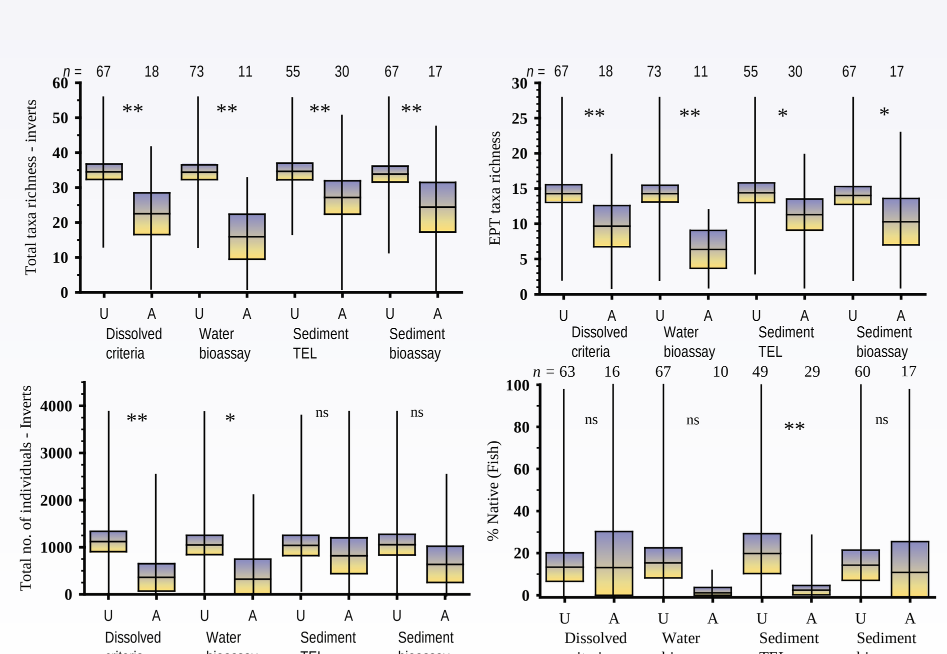

Figure 2. Comparison of selected metrics between groups identified as affected or unaffected by the individual endpoints. Boxes = mean and 95% CLs (each metric for each group); whisker = range; n = no. reaches classified in each group; U = unaffected group; A = affected group; ns = not significant; * = p < 0.05; ** = corrected probabilities significant (i.e., sequential Bonferroni technique).

Table 4. Enumeration of sampling events where classification based on the individual-effects measures and that based on the metric disagree. Total number of sampling events = "Classified as unaffected" + "Classified as affected".

Metric	Classified as unaffected	Metric < 95% LCL for unaffected group	Classified as affected	Metric > 95% UCL for affected group
Dissolved chronic criteria (water)				
Total taxa rich. (inverts)	67	28	18	6
Total no. of individuals	67	36	18	1
Ephemeroptera taxa rich.	67	22	18	7
EPT[c] taxa rich.	67	20	18	4
Water bioassays				
Total taxa rich. (inverts)	73	29	11	3
Ephemeroptera taxa rich.	73	24	11	2
EPT taxa rich.	73	25	11	4
Chironomidae taxa rich.	73	32	11	3
Sediment TELs				
Total taxa rich. (inverts)	55	21	30	13
Ephemeroptera taxa rich.	55	25	30	9
Shredder taxa rich.	55	30	30	8
% Ind., native species	49	39	29	0
Sediment bioassays				
Total taxa rich. (inverts)	67	26	17	7
Intolerant taxa rich.	67	22	17	6
Tanytarsini taxa rich.	67	23	17	4
%Tanytarsini (Chironom.)	67	33	17	2

- There are reaches where the methods appear to differ in their assessment of adverse effects (Table 4). Reaches in the unaffected groups where metrics are < the 95% LCL may be affected by other stressors. Previous analyses identified effects associated with livestock grazing as another stressor in these streams. Also, the streams were only sampled once, and we could not assess the temporal variability of metals.
- At reaches in the affected group where metrics were > the 95% UCL, metals exposure may differ from that measured, because of unaccounted effects on bioavailability. The AWQCs are adjusted for hardness. The TELs do not consider factors affecting metal bioavailability.

- For water, the regressions of metrics on the summed ratios of the four metals to their chronic AWQCs changed when at least one metal exceeded its AWQC (Figure 3), suggesting the AWQCs approximate thresholds for adverse effects in these streams.
- For sediments, the regressions of metrics on the summed ratios of the metals to their TELs did not change when at least one metal exceeded its TEL, suggesting the TELs do not approximate thresholds for adverse effects in these streams. A threshold for adverse effects may be less than the TELs.

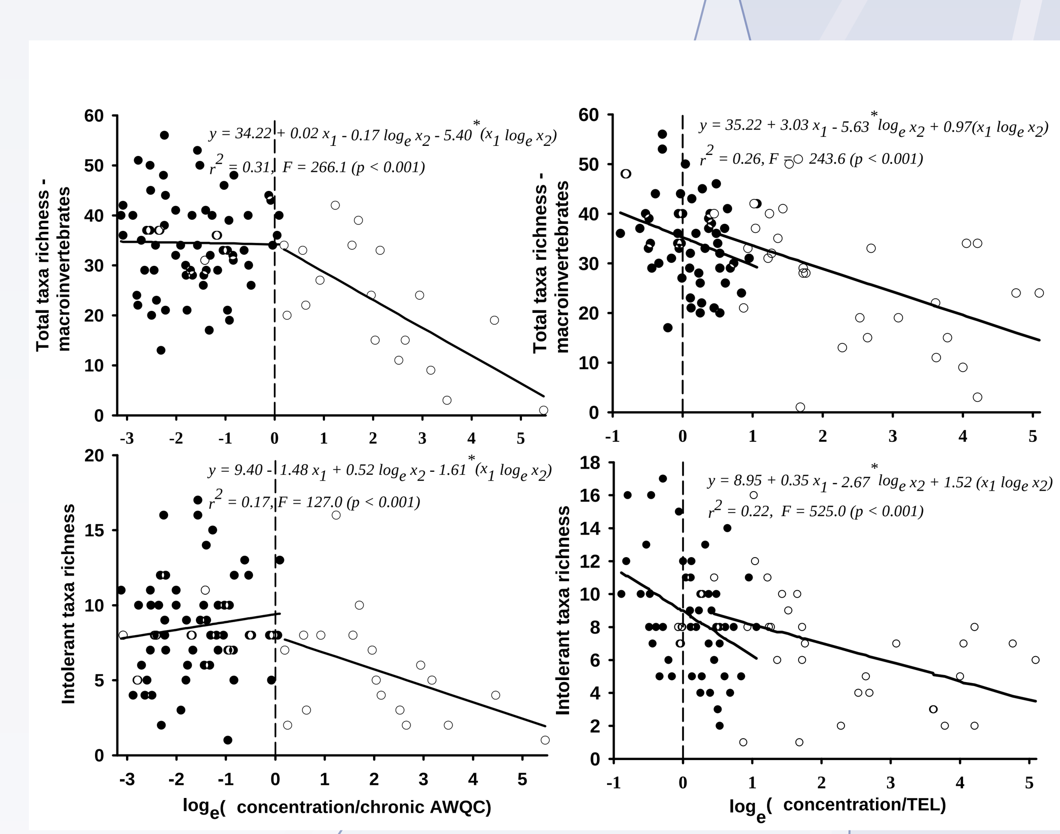

Figure 3. Segmented regressions of metrics on the summed ratios of either dissolved metals to their chronic AWQCs or sediment metals to their TELs. In the regressions, y=the metric value; x1 (dummy variable)=1 if at least one metal exceeds its threshold (open ciricles), or x_1=0 otherwise (solid circles); and x_2= Σ (ratios of dissolved Cd, Cu, Pb, and Zn to their chronic AWQCs) or Σ (ratios of sediment Cd, Cu, Pb, and Zn to their TELs). *=different from 0 (p<0.05). Solid lines are the predicted regression lines.

- Besides assessing measurement endpoints at different levels of biological organization, criteria, bioassays, and metrics differ in their stressor specificity. Criteria are specific to measured contaminants and ignore unmeasured stressors or those lacking criteria. Bioassays detect any bioavailable toxicants in the test medium but do not assess other characteristics. Metrics are not stressor specific. While metrics may be sensitive to specific stressors, they also may be sensitive to other concurrent stream alterations, such as alterations of physical habitat, that are not addressed by criteria.

Conclusion

- We used a simple approach in classifying reaches into unaffected and affected groups. This recognizes that it has been difficult to construct models to extrapolate from individual to population to community effects, because of difficulties of incorporating variation in exposure and response across the hierarchical levels of time, space, and organization.
- Considering this simple classification, one might expect few, if any, metrics would exhibit differences between the two groups.
- However, a number of metrics, particularly richness metrics, exhibited differences between groups. This suggests that a relationship exists between the individual-level effects assessed by criteria or ambient bioassays and the community-level effects assessed by metrics and that the individual-level effects are predictive to some extent of community-level effects.
- We need to assess the generality of these relationships for other contaminants besides metals.

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